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Art. XV.—*Dacites and Associated Rocks at Arthur's Seat, Dromana.*

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Introduction.

Arthur's Seat (1,031 feet) is a prominent hill of igneous rocks 44 miles south of Melbourne. It is situated near Dromana, and presents a bold, steep face to the eastern shore of Port Phillip Bay (fig. 1). It consists of granite capped with hornblende dacite, rhyodacite and Tertiary river gravels. The granite is overlain by basalt to the south-west of Arthur's Seat, and granitic gravel covers the eastern flanks.

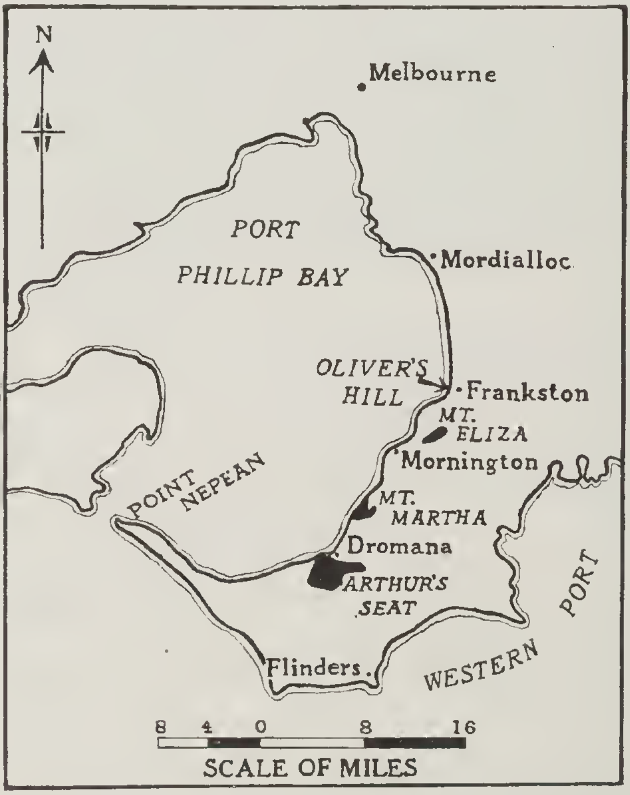

Fig. 1. Sketch map of the Mornington Peninsula showing outcrops of granitic rocks in black.

The granitic rock was originally described as syenite (12, p. 219), and later as granodiorite (15, p. 136). The geological map accompanying this paper was taken from a map prepared by R. A. Keble, of the Geological Survey of Victoria, and to his map the dacite and aplite outcrops recently discovered on Arthur's Seat have been added.

The main ridges in the area, which consist of granite and older basalt, strike in a north-south direction; on the east and west, these ridges slope into plains of Pleistocene and Recent deposits. The main drainage of the area is effected by Splitter's Creek. This creek rises near the Lookout Tower, and flows in a southerly direction to join Main Creek, which empties into Bass Strait about 7 miles west of Flinders. Small, deep gullies drain the northern sides of Arthur's Seat, and their trend has been determined by the strike of the more prominent dykes and joints in the granite.

It is difficult to judge how far faulting has affected the topography of the Arthur's Seat area. A suggestion was made by Professor J. A. Bartrum during the 1935 excursion of the Australian and New Zealand Association for the Advancement of Science to this area, that the bold seaward face of Arthur's Seat might represent the recently uncovered wall of a stock rather than an escarpment formed along Selwyn's Fault Zone. There are, however, more indications of faulting along the seaward face of Arthur's Seat than elsewhere. Numerous slickensides and granulation of the rocks in several narrow shear zones occur near and along the joint planes of the igneous rocks. The presence of very numerous, closely spaced joints along the northern (seaward) face is suggestive of movements in Selwyn's Fault Zone. Still more definite evidence of faulting is present in quarry 5, at The Rocks in the north-west portion of the area, where a dyke of felspar hornblende porphyrite has been step faulted sixteen times in a distance of 50 feet. The faulting is post-Devonian in age, and may perhaps be associated with Tertiary to Pleistocene or Recent movements which caused the elevation of the conglomerate and sands at The Rocks.

Dacites.

The dacite series occurs within an area of a little more than a quarter of a square mile around the summit of Arthur's Seat, and comprises hornblende dacite on the east and rhyodacite on the west (fig. 2). The contact between the two types of dacite is masked by detritus and soil. Occasional contacts between the hornblende dacite and the granite are observable, and a few small, rounded sedimentary xenoliths occur in the hornblende dacite east of the Lookout Tower. Rhyodacite has been exposed in contact with the granite in road cuttings along Tower Road between Murray Memorial and Chapman Memorial (fig. 2), and it extends south-eastwards to the summit of Arthur's Seat. West of the road cuttings, it extends down steep slopes for 100 feet below the level of the road. A small outcrop of rhyodacite occurs above the road cutting at Murray Memorial, isolated from the main outcrop by about a quarter of a mile.

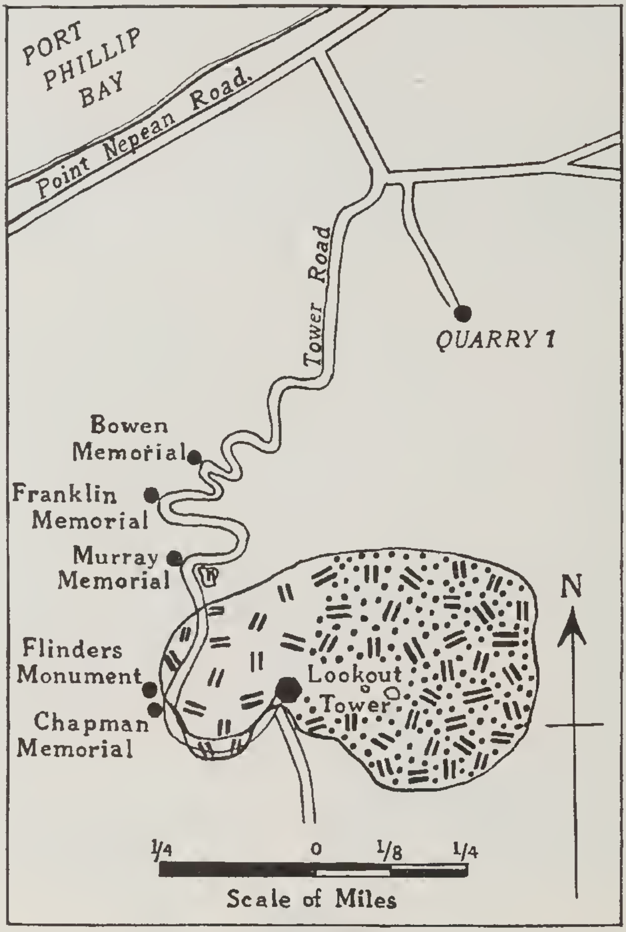

Fig. 2. Sketch map showing locations along Tower Road, and the outcrop of Dacite. Hornblende Dacite in the East (dotted), and Rhyodacite in the Western portions of the outcrop.

The rhyodacite outcrop thins out towards the higher levels of Arthur's Seat, so that present exposures present a pocket-like appearance, suggestive of the lower limits of a roof pendant. The rhyodacite has weathered in parts to a crumbly mass of clay, and is sometimes very much stained by secondary iron oxides. Closely-spaced joints in the upper portions of the rhyodacite exposed in road cuttings above Murray Memorial give rise to a pebbly structure on weathering.

No clearly marked metamorphic changes are visible in the dacites along contacts with the granite, although the grain size is sometimes a little coarser than usual in portions of the rhyodacite; no schistosity has been developed as at Selby (18) or Warburton (6). The dacites are older than the granite, however, since microscopic examination of contact specimens provides clear evidence of metamorphism. Furthermore, igneous veins derived from the granite have invaded the dacites, the lower limits of which show irregular embayed junctions with the granite, and small xenoliths of rhyodacite are included in the intrusive rock. The dacites are therefore pre-Granitic in age, and since they contain inclusions of sedimentary rocks which are likely to be portions of the Ordovician bedrock of the Mornington Peninsula, they are probably post-Ordovician. By analogy with occurrences of dacite in other parts of Victoria, they may be regarded as having been extruded in Upper Devonian times, while the granite is a later stage in the Palaeozoic igneous history, probably late Upper Devonian to early Carboniferous (10).

A dyke of felspar-hornblende porphyrite, 9 inches wide, cuts the granite at an angle of 45 degrees, for a distance of 50 feet on the seaward face of quarry 5, at The Rocks. About 100 yards north-east of quarry 5, a decomposed dyke, probably allied to the felspar-hornblende porphyrite, is 2 feet wide and winds in an irregular manner through the granite, as depicted diagrammatically in fig. 3. These dykes are probably genetically related to the dacites of the Dromana area, because similar dykes are allied to the dacites occurring at Selby (18) and at Warburton (6).

Granite.

Soil, vegetation and granitic detritus mask exposures of the granite at Arthur's Seat. No large tors are developed, and the study of the granite is confined to exposures made by quarrying and road cutting. Of the various quarries indicated by numbers on the map, No. 1 has been cut in aplite, Nos. 6 and 7 in granite porphyry, Nos. 5 and 9 in contaminated granite, and the remainder in normal granite.

An evenly spaced set of joints has been recorded at a quarry $2\frac{1}{2}$ miles east from Dromana jetty, and their strike is given as east-west and north-south (15, p. 136). This quarry is situated in the eastern portion of the granite exposure. On the northern sides of Arthur's Seat, the granite possesses numerous, very closely spaced joints, two sets striking W. 20° N. and W. 35° N., and two sets striking N. 15° E. and N. 25° W. The joints in the eastern part are sufficiently widely spaced to permit quarrying for building stone, but those in the northern portion of the area are seldom over 9 inches to 1 foot apart, making the granite useless for the extraction of blocks of a size requisite for building purposes.

Xenoliths are scarce in the main mass of the Dromana granite. A few are present near the rhyodacite contact between Murray Memorial and Chapman Memorial. A local concentration of xenoliths occurs between quarry 5 and quarry 9 at The Rocks, where the granite has become contaminated and the inclusions hybridised. Several large angular xenoliths of sedimentary origin have been exposed by quarrying, also relatively unaltered and granitised hornblende diorite which forms patches and schlieren in the contaminated granite at this locality (fig. 3).

The large undigested xenoliths of altered sediments associated with the schlieren may indicate the proximity of the Ordovician wall rock. If this is so, the hornblende diorite might represent the chilled edge of a stage in the differentiation of a dioritic magma which ultimately gave rise to the granite of this area. On the other hand, the schlieren may represent dykes of hornblende diorite which were originally injected into Ordovician sediments, and subsequently became partially absorbed by the granite magma.

Dykes associated with the late phases of the intrusion of the granite in the Dromana area consist of granite porphyry, granophyre, felspar porphyry, microgranite, graphic granite, aplite and quartz.

Granite porphyry occurs at quarries 6 and 7, where its relation to the granite is probably that of a dyke, though contacts are masked by products of weathering. A similar dyke about a foot wide cuts the granite at The Rocks. A dyke of granophyre, 4 feet wide, separates the granite from the rhyodacite in the road cutting above Murray Memorial. Between this dyke and the granite, a narrow, sheared and granulated zone has been produced, probably as a result of faulting. Narrower dykes of granophyre traverse the granite near Murray Memorial.

Felspar porphyry dykes, about 6 inches wide, intrude the granite at Chapman Memorial, and a similar, but slightly wider dyke cutting the granite just below Murray Memorial, contains veins of pink orthoclase.

Microgranite forms a dyke 30 feet wide at Flinders Monument, where it is cut by veins of aplite. Graphic granite is present in the road cutting between quarry 4 and quarry 5, and a narrow vein traverses the contaminated granite of quarry 5 (fig. 3). A prominent, closely jointed dyke of aplite, 50 feet wide, strikes north-north-west near Flinders Monument, and small offshoots from it sometimes have very dense, dark, fine-grained borders. Dykes and veins of aplite intrude the hornblende dacite about half a mile east of the Lookout Tower, whilst a larger intrusion occupies a considerable area around quarry 1. Two fine-grained dykes of aplite cut through the granite porphyry of quarry 6, and numerous veins and dykes are exposed along the Tower Road cuttings, especially near Bowen Memorial. They ramify through portions of the granite in a sinuous manner, but are straight and parallel where confined to joint planes.

Quartz veins have been injected into the granite and rhyodacite in the vicinity of Murray Memorial, and between Chapman Memorial and the summit of Arthur's Seat. They also occur at The Rocks in the north-west portion of the area.

Tertiary Rocks.

The south-eastern portion of the area on the accompanying map is covered by basalt as mapped by R. A. Keble. Outcrops of the fresh rock are scarce, and the basalt has weathered to a red-brown soil, cultivated for fruit growing. This area of basalt is probably connected with flows in the Cape Schanck-Flinders district, which are considered to belong to the Older Volcanic Series of Victoria.

River gravels, mapped by R. A. Keble, occur near the summit of Arthur's Seat, about half a mile south-east of the Lookout Tower. Exposures are to be observed in shallow road cuttings and attached to the roots of fallen trees. They locally form a thin veneer to the granite, and have not been observed associated with the dacite series. They contain rounded pebbles, ½ to 3 inches across, of white quartz, compact and laminated quartzite, hornfels, grit, sandstone, micaceous sandstone, aplite, granite, pegmatite, and rare basalt and jasper. Occasional boulders of quartzite up to 1 foot long are also present.

A bed of conglomerate, with occasional boulders of ferruginous grit, rests on a wave-cut platform in the granite at The Rocks. It is overlain by 30 to 40 feet of sands containing occasional pebbles (fig. 3).

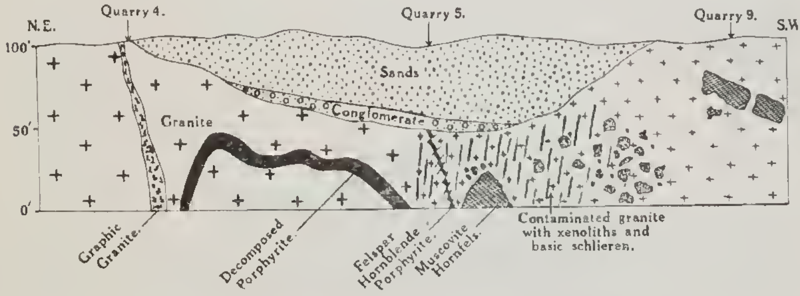

Fig. 3. Diagrammatic section at The Rocks, Dromana.

The conglomerate varies in thickness from a few inches to 3 feet. The average size of the pebbles is 4 inches, and they are set in a sandy to gritty base which has been partly cemented by iron oxide, producing local patches of hard ferruginous grit.

The pebbles in this conglomerate consist of smooth, rounded, and sub-angular and pitted fragments of granite, aplite, hornfels, hybrid rock and hornblende diorite. Rare pebbles of an augite dacite are also present, and since all of the pebbles in the conglomerate were obviously derived from a former adjacent coastline, augite dacite must also have been present in this district, although no outcrops of it have been located in the neighbourhood.

No fossils were found in the conglomerate, but its age is probably late Tertiary or Pleistocene. It is 40 feet above sea level at the eastern end, and 15 to 20 feet above sea level 100 yards to the west. The dip is 7 degrees to the west, and may represent the original angle of rest on the surface of the granite, or tilting may have accompanied the elevation above sea level. The deposit extends from the face of the road cutting (i.e., into the cutting face) for a distance of 3 feet. Before the construction of the road, it was about 80 feet in this direction, and had a distinct tilt seawards.

Marine sands, which are probably Pleistocene in age, occupy the flatter portions of the area around Arthur's Seat, whilst Recent sands and gravels form a plaster to the older rocks. At quarry 6, angular fragments of granite have been recemented in a fine-grained matrix forming breccia.

Petrology of the Dacites.

The dacites include hornblende dacite and rhyodacite, and their mineral compositions are shown in the following table of micrometric analyses. The accessory minerals included in table 1 consist mainly of ilmenite.

Table 1.

	1.	2.	3.	4.	5.	6.	7.	8.	9.
Quartz	2·97	30·5	29·8	27·4	9·56	20·82	11·46	13·18	1·22
Plagioclase ..	21·66	38·5	33·6	23·4	15·30	21·32	27·04	28·92	24·13
Orthoclase ..	..	21·2	25·6	35·3					
Hornblende ..	8·30	0·3	5·2	8·1	..	..	..	..	..
Hypersthene ..	..	..	..	..	..	..	1·63	6·24	12·17
Biotite	3·86	6·8	4·0	1·6	3·82	10·22	13·95	4·28	10·96
Accessories ..	1·78	2·7	1·8	4·2	..	..	..	..	1·08
Groundmass ..	61·42	..	..	..	72·32	47·64	45·65	48·00	50·44

1. Hornblende Dacite, Dromana.
2. Biotite Rhyodacite, Dromana.
3. Hornblende-Biotite Rhyodacite, Dromana.
4. Hornblende Rhyodacite, Dromana.
5. Quartz Dacite, Healesville.
6. α Quartz-Biotite Dacite, Warburton.
7. β Quartz-Biotite Dacite, Warburton.
8. Quartz-Hypersthene-Biotite Dacite, Black Spur.
9. Hypersthene Dacite, Upwey.

The above table illustrates the absence of orthoclase in the hornblende dacite, and its relative abundance in the rhyodacite types. The table also indicates the amount of the microcrystalline groundmass in the hornblende dacite, whereas in the rhyodacite, all the groundmass constituents were sufficiently large to be identified and measured by the micrometric method.

Micrometric analyses of dacites from Warburton (6), Black Spur (5), and Upwey (18) are added to table 1 for purposes of comparison with the Dromana examples. From the table, it is seen that the Dromana hornblende dacite is generally less acidic than the dacites from these other Victorian localities. The percentage increase of hornblende in the rhyodacite types from Dromana indicates the amount of this mineral generated by thermal metamorphism.

The heavy mineral assemblages of the dacites consist of hornblende, biotite, apatite, zircon, magnetite and ilmenite. Rare garnet and epidote in contact types, and occasional pleochroic cores to apatite crystals, also occur. The index figures are as follows:—

	Index Number.	Specific Gravity.
Hornblende Dacite	5.6	2.68
Biotite Rhyodacite	1.5	2.61

Rhyodacites.

Hand specimens of the rhyodacite resemble the Marysville rhyodacite (11), but thin section examinations show that the microcrystalline groundmass of the Marysville occurrence is not so well developed at Dromana, where a certain amount of recrystallisation has taken place as a result of thermal metamorphism. Phenocrysts of orthoclase-perthite and oligoclase sometimes possess lacineal borders and associated myrmekite (9), and separated patches of quartz are often in optical continuity. Large areas of ilmenite are surrounded by clusters of small biotite flakes (18), whilst the accessory minerals are apatite, zircon and rare crystals of sphene and pyrite. The hornblende is pale green in colour, possesses crenulate boundaries, sieve structure and abundant small inclusions of iron oxide, factors which indicate that the hornblende is a thermal metamorphic product in the rhyodacites.

Hornblende Dacite.

The hornblende dacite is a porphyritic rock with embayed phenocrysts of quartz, brownish-green primary hornblende, occasional brown biotite developed as a reaction product between the acid groundmass and ilmenite, and corroded and zoned phenocrysts of oligoclase. Criss-cross fibres of pale green hornblende, which is probably secondary in origin, are partially altered to biotite. Specks of sulphide minerals are visible in the hand specimens of the hornblende dacite. The microcrystalline groundmass consists of quartz, oligoclase, ilmenite, biotite and pale green hornblende. Chlorite is occasionally associated with small crystals of sphene, and the accessory minerals are zircon and apatite. The felspar phenocrysts are sometimes zoned with inclusions of sphene and green chloritic material, and often possess pale greenish cores, due to the presence of hosts of dust-like inclusions and chloritic decomposition products. Where certain of the oligoclase phenocrysts possess blocky structure, this has been produced by intergrowth with small amounts of orthoclase introduced from the intrusive granite.

Felspar-Hornblende Porphyrite.

Dykes of felspar-hornblende porphyrite have a microporphyritic texture. The fine-grained groundmass constituents show flow structure, and consist of biotite, magnetite, apatite, laths of labradorite, small plates of hornblende, epidote and hematite. The micro-phenocrysts are labradorite and small elongated crystals of green uralitic hornblende containing numerous grains of iron ores. Occasional nests of secondary, pale green hornblende are invariably surrounded by rings of small biotite plates and granular epidote.

The decomposed dykes of felspar-hornblende porphyrite consist of abundant laths of rather altered labradorite, set in a clayey base, stained with limonite.

These dykes are finer-grained than those from Warburton (6) and Selby (18), which contain much larger crystals of hornblende, and usually do not show flow structures except at the edges. At Dromana and Selby, the felspar-hornblende porphyrite dykes are post-granitic intrusions, but at Warburton they are pre-granodiorite, so that in the first two localities these dykes, which are more basic than the rocks which they intrude, would represent a basic layer of magma situated below the consolidated granitic rock.

Xenoliths in the Dacite.

Xenoliths of sedimentary origin in the hornblende dacite at Dromana, are comparable with sedimentary xenoliths recently observed in the propylitised dacite of Hesket, in the Macedon district. In both of these localities, the xenoliths are sporadic in occurrence, small and rounded, and have been subjected to only slight alteration, with practically no reconstitution after engulfment in the dacites. There is very little indication of strewing about of the xenolithic material in the dacite lava, and almost no embayment or corrosion is shown along junctions.

In each locality, the xenoliths consist of very fine-grained mica hornfels, derived from the bedrock of Ordovician shales through which the dacitic lavas were extruded.

Alteration of the Dacites by the Granite.

Pools of quartz in optical continuity and a coarser texture along parts of the contact, indicate partial recrystallisation of the constituents of the rhyodacite by the granite. The ferromagnesian content of the rhyodacite changes in both nature and amount as parts of the contact are approached. The sequence outwards is hornblende rhyodacite, hornblende-biotite rhyodacite, to biotite rhyodacite. At the Murray Memorial area, hornblende is present practically to the complete exclusion of biotite, resulting in the production of hornblende rhyodacite. A little further from the contact, hornblende and biotite are almost equal in proportion, giving rise to a hornblende-biotite rhyodacite, but at a still greater distance, biotite is the chief ferromagnesian mineral in a biotite rhyodacite. These relationships are shown in columns 4, 3, and 2 of table 1. With increasing distances from the contact, there is also an increase in quartz, plagioclase and biotite, and a decrease in orthoclase and accessory minerals (table 1). Micrographic intergrowths replace lacineal borders in the hornblende rhyodacite, and the microcrystalline groundmass is absent. In the hornblende-biotite zone, remnants of the groundmass and abundant lacineal borders occur, and furthest from the contact, the biotite rhyodacite has a slightly increased proportion of groundmass, and shows little sign of contact metamorphism.

The development of hornblende at the expense of biotite as contacts are approached, has also been described from the Warburton district, where granodiorite is intrusive into a dacite series (7, p. 185). The production of secondary hornblende from a reddish-coloured form of biotite, has been indicated at Mt. Leinster in Eastern Victoria (3), where syenite has intruded granodiorite. A certain amount of a reddish biotite occurs in the thermally metamorphosed rhyodacite at Arthur's Seat, in addition to the ordinary greenish-brown variety, but the reaction has not continued as far as at Mt. Leinster, where hornblende inverts to augite at the contact. Parallel alterations at Arthur's Seat and Mt. Leinster are, the increase of the potash felspar content as the contact is approached, the absorption of quartz as the ferromagnesian minerals invert to higher termperature forms, and the presence of micrographic intergrowths between quartz and orthoclase in the thermally altered rocks.

Contact metamorphism is not well marked in the hornblende dacite at Arthur's Seat, mainly on account of lack of good contact exposures. At junctions with small irregular portions of the roof of the granite intrusion, and in boulders not *in situ,* the groundmass of the hornblende dacite shows partial recrystallization of quartz and felspar.

Petrology of the Granite.

The granite is a medium, even-grained rock with abundant greenish orthoclase. In thin section, it consists of quartz, orthoclase-perthite, oligoclase and biotite. The oligoclase is often blocky due to intergrowth with orthoclase, and sometimes possesses saussuritised cores. Muscovite is secondary after plagioclase, epidote occasional and myrmekite rare. Hornblende is generally confined to areas where assimilation of hornblende diorite has occurred, and so it is a contamination mineral in the granite. The accessory minerals consist of sphene, zircon, ilmenite, and apatite. The sphene is usually associated with the hornblende and may likewise be a contamination mineral. The felspars are often cloudy from abundant sericite, chloritic material and kaolin. Optically continuous patches of quartz fill the interspaces between some of the felspar crystals, and where such quartz patches occur, myrmekite and micrographic intergrowths are abundant.

Biotite and hornblende crystals which possess sieve structures and associated grains of ilmenite, may represent remnants of igneous xenoliths. Some of the larger oligoclase crystals indicate regrowth, by jacketting with later formed more acid oligoclase. Granulation and stringing out of the minerals in the granite has occurred along small shear planes.

Modified rapakivi structures (2, p. 219) occur in a very restricted manner at the contact between a small tongue of granite and hornblende dacite, east of the Lookout Tower. Rapakivi ("crumbly stones") are described by Sederholm as granites containing ovoids, four to ten centimetres across, consisting of orthoclase or microline surrounded by a rim of oligoclase (16, p. 75). The Dromana occurrences are not visible in the hand specimen; under the microscope, structures resembling rapakivi are five millimetres across, ovoid to sub-rectangular crystals of orthoclase-perthite being mantled by a continuous rim of oligoclase 0.3 to 0.5 mm. wide. In one example, almost in direct contact with the hornblende dacite, a wider rim of oligoclase is intergrown with orthoclase. Quartz and biotite occur in the orthoclase core, micropegmatitic intergrowths in the oligoclase mantles, and small pools of granitic material in both, similar to examples described by Sederholm (16). The rounded nature of the orthoclase ovoids is considered by Sederholm to result from defective development of crystal forms as a result of impurity (17, p. 92).

Wells and Woolridge consider that potash felspar with a surround of oligoclase such as described above, reflects the increasing basicity of the magma as contamination progresses (20, p. 198). Sederholm doubts whether rapakivi granites are differentiation products, and considers that many of them are syntectic rocks formed by assimilation of older rocks (17, p. 84). In agreement with Sederholm's view, the local development of "micro-rapakivi" structures in granite at Dromana, is considered to be due to assimilation, since the dacite has been partially engulfed by granite. The structures are not the result of basification by contamination, such as was found by Wells and Woolridge, because the Dromana granite has assimilated a relatively acidic rock, dacite, whereas Wells and Woolridge describe the development of these rapakivi structures in granite, as resulting from the assimilation of gabbro. At Dromana, the rapakivi structures in granite at its contact with the dacite, are considered to have arisen locally, from a slight marginal increase in the soda content of the magma, consequent upon the assimilation of dacite, producing a second generation of oligoclase.

The mineral composition of the Dromana granite is shown in table 2, in which the "accessory minerals" consist mainly of ilmenite and apatite. Micrometric analyses of the You Yangs granite (1), and of the granodiorites at Mt. Eliza (19), Macedon, Warburton (6), and Frankston, have been added for comparison. The trace of hornblende in the Warburton granodiorite was discovered during the heavy mineral analysis of this rock. The silica percentages given in the table, have been computed from the results obtained from the Rosiwal micrometric analyses.

TABLE 2.

	1.	2.	3.	4.	5.	6.
Quartz	34·8	28·7	29·37	26·3	28·1	35·88
Orthoclase	33·9	34·8	17·59	6·6	12·4	21·71
Plagioclase	24·9	25·5	39·87	38·1	34·5	28·57
Biotite	4·3	8·8	12·23	27·3	24·0	11·40
Hornblende	1·5	1·3	0·59	..	tr.	0·08
Accessories	0·6	0·9	0·30	1·7	1·0	2·36
Specific Gravity	2·63	2·65	2·70	2·72	2·72	2·64
Silica Percentage	75	71	69·5	64	65	72

1. Granite, Dromana.
2. Granite, You Yangs.
3. Granodiorite, Mount Eliza.
4. Granodiorite, Macedon.
5. Granodiorite, Warburton.
6. Granodiorite, Oliver's Hill, Frankston.

The above table shows that the Dromana granite contains more quartz and less biotite than the You Yangs granite, but the other constituents are more or less equivalent in amount. The granodiorites in table 2 have a lower quartz and orthoclase content, and a greater amount of plagioclase and biotite. Although the Dromana granitic rock was referred to by its trade name of "granite", it was stated that the proportion of orthoclase to plagioclase felspar was less than one to two, and so the rock was classified as a granodiorite (15, p. 136). The Rosiwal analysis in table 2, however, indicates an excess of orthoclase in the ratio of two to one and a half. The silica percentage is much higher than that of average granodiorite. In addition, the Dromana granite contains abundant microperthite which is a feature regarded by Johannsen as characteristic of granites and rare in granodiorites.

The granodiorite of Oliver's Hill (table 2, column 6), has a rather high silica percentage for a granodiorite, and it is regarded as representing a more acid offshoot from the Mt. Eliza granodiorite.

The heavy mineral indices and assemblages shown in table 3, elaborate the minera'ogical comparison of the Dromana granite with the gray granodiorites outcropping in the Mornington Peninsula at Mt. Martha, Mt. Eliza, and Oliver's Hill, Frankston.

Table 3.—The Heavy Minerals of the Granitic Rocks of the Mornington Peninsula.

	1.	2.	3.	4.
Index Number	3·4	7·1	8·3	12·4
Specific Gravity	2·63	2·58	2·64	2·70
Anatase (blue)	V	..	..	..
Andalusite (pale green)	..	..	..	V
Apatite (colourless)	o	C	C	C
Apatite (with pleochroic cores)	r	V	V	V
Biotite (greenish-brown)	a	..	..	..
Biotite (brown)	o	A	A	A
Chlorite	o	V	o	o
Epidote	r	..	V	..
Garnet	..	V	..	o
Gold	V	..	..	..
Hornblende (greenish-brown)	C	o	r	a
Ilmenite	..	r	C	r
Magnetite	C	r	..	V
Orthite	..	..	..	V
Pyrite	o	r	..	o
Pyrrhotite	V	..	..	..
Rutile	..	V	..	..
Sphene	o	V	..	o
Tourmaline (blue)	..	..	..	V
Zircon (colourless)	C	C	C	C
Zircon (pale yellow)	..	V	..	..
Zoisite	V	..	..	..

A = very abundant; a = abundant; C = common; o = occasional; r = rare; V = very rare.

1. Granite, Dromana.
2. Granodiorite, Mount Martha.
3. Granodiorite, Oliver's Hill, Frankston.
4. Granodiorite, Mount Eliza.

The variation in the index numbers of these granitic rocks is due to the degree of differentiation, the amount of assimilation and the nature of the country rocks through which the magmas were injected.

In each example, inclusions in zircon crystals are relatively common, and the crystals are sometimes zoned at Dromana, Oliver's Hill, and Mt. Martha. Stout, stumpy crystals are very rare in the Mt. Eliza, Oliver's Hill, and Mt. Martha granodiorites, and very rare "torpedo" forms (1) occur in the Dromana granite. Andalusite, which occurs in the Mt. Eliza granodiorite, has also been recorded from the adjacent contact slates of the Moorooduc quarry. Rutile from the altered sediments, and hornblende, biotite, and apatite from the granodiorite were also recorded from the granodiorite from thin section examinations (19). One grain of anatase was observed in the Dromana granite, and none in the granodiorites outcropping to the north. Apatite is more abundant in types richer in biotite and hornblende, i.e., in the northern outcrops. Some of the apatite crystals are bluish at Dromana, pale yellowish-green at Mt. Martha and the majority are colourless. At Mt. Eliza and Oliver's Hill, all of the apatite crystals are colourless. One crystal of orthite in the Mt. Eliza granodiorite, has been observed in thin section.

Although the granite of Arthur's Seat was intruded into dacite and Ordovician rocks, its heavy mineral assemblage and index number indicate that few contamination minerals, either as xenocrysts or as the result of processes of contamination, were generated from the invaded rocks, or that if contamination products were added to the magma in the early stages of intrusion, such products have sunk from view. The Mt. Martha granodiorite was intruded into more extensively developed argillaceous rocks, from which a considerable amount of biotite was generated and added to the magma, and less sinking of newly formed basic minerals occurred. At Mt. Eliza, conditions were likewise favorable for the generation of biotite, but either in greater quantity than at Mt. Martha, or else with considerably less sinking of assimilation products. At Mt. Eliza, andalusite and garnet were also added to the magma as xenocrysts.

The differences existing between these granitic rocks exposed in neighbouring outcrops in the Mornington Peninsula (fig. 1), indicate that although they may have all been initially derived from a common magma chamber, differentiation and sinking of assimilation products continued further in the Dromana example, than in the granodiorites occurring to the north.

Xenoliths in the Granite.

The xenoliths in the Dromana granite have been derived from two sources, from sedimentary rocks, and from igneous rocks.

Argillaceous Ordovician rocks which became enclosed in the granitic magma, have been converted into muscovite hornfels consisting of an interlocking aggregate of quartz grains, laths of muscovite, and abundant scattered grains of iron ores. Brown tourmaline of pneumatolytic origin occasionally wraps around some of the quartz crystals, whilst prisms of foxy-red and yellow rutile have recrystallised from the original titaniferous minerals in the sedimentary inclusions. Small laths of biotite are occasionally developed, and well rounded crystals of zircon are present.

Coarser grained portions of these sedimentary inclusions are slightly schistose, and the borders of the larger inclusions are sometimes inshot with granitic material. Smaller xenoliths consist of a mosaic of quartz and pale green micaceous material. Biotite plates contain sagenitic webs of sphene, and minute pyritohedra of pyrite are included in the quartz grains.

The heavy mineral assemblage of these xenoliths is made up of abundant prisms of yellow-green to dark brown tourmaline, with ilmenite, rutile, apatite, rounded zircon, biotite, andalusite, muscovite, and rare staurolite.

The xenoliths of igneous origin have been derived either from hornblende diorite or from rhyodacite.

Xenoliths derived from the hornblende diorite consist of biotite and laths of oligoclase with numerous embedded grains of apatite. Occasional pools of quartz have been introduced from the granite magma, and the granite at contacts with some of these xenoliths contains poikilitic oligoclase bearing inclusions of epidote, biotite, ilmenite, and apatite derived from the xenoliths, whilst patchy intergrowths occur between orthoclase and oligoclase.

Xenoliths derived from the rhyodacite are finer in texture than the parent rock, and types from both the biotite and the hornblende-biotite rhyodacites have been recognised. Sieve structure is more marked in the ferromagnesian minerals of the xenoliths than in the contact rock, whilst ilmenite grains and apatite needles are more abundant.

Infiltration of granitic material has given rise to poikilitic oligoclase and orthoclase-perthite associated with quartz pools. The granite at junctions with these xenoliths contains abundant myrmekite, blocky felspars, and partially digested minerals, sometimes with lacineal borders, derived from the xenoliths.

Hybrid Rocks.

Much of the hornblende diorite, which usually occurs in well defined bands at The Rocks, has been hybridised by the granitic magma. Stages are represented in which hornblende, biotite, oligoclase, and orthoclase are present in variable amount.

Secondary quartz has been moulded on the felspars, and occasional crystals of sphene are associated with the hornblende. The accessory minerals are abundant apatite and iron ores with some zircon.

In less banded portions of the hornblende diorite schlieren at The Rocks, the hornblende is more prominently altered to biotite, and more granitic material has been introduced. These dark streaks and patches of hornblende diorite finally become distributed through the surrounding magma, forming a contaminated granite.

The specific gravity of sampled portions of the hybrid rock is 2.58, the low figure being due to alteration. The index number is 39.3, and most of it is composed of hornblende. Some of the apatite crystals in the heavy mineral assemblage contain dark coloured cores which are pleochroic and often sharply defined from the clear outer zone (8). The pleochroism is from dark blue and purple to light brown, and occasionally, darker lines of the colouring matter appear as dustlike inclusions along imperfect basal cleavage planes in the apatite. Similar occurrences are met with in the dacite and granite in the Dromana district.

Granitic Dykes.

In the granite porphyry, sericitisation of the felspars and regrowth around some of the phenocrysts, indicates that the rock has suffered late magmatic changes. Corroded phenocrysts of quartz, biotite, orthoclase-perthite, and oligoclase are set in a fine-grained groundmass of similar minerals, with accessory zircon, apatite, rare ilmenite, and magnetite. Oligoclase phenocrysts are often blocky where intergrown with orthoclase.

In the granophyre, the groundmass consists almost entirely of micrographic and cryptographic intergrowths of orthoclase and oligoclase with quartz. A few phenocrysts of quartz and orthoclase with occasional frameworks of micro-pegmatite are present. The specific gravity of the granophyre is 2.64, and the index number 2.7, the heavy minerals consisting of apatite, zircon, ilmenite, foxy-red rutile, biotite, hornblende, chlorite, and limonite.

The felspar porphyry consists of phenocrysts of orthoclase, oligoclase, occasional rounded and embayed quartz, and rare biotite, set in a fine-grained groundmass of similar minerals. Abundant ilmenite, apatite, rutile, and hematite, with occasional zircon and rare myrmekite are also present in the groundmass.

The microgranite consists of an interlocking aggregate of quartz and orthoclase-perthite, with idiomorphic oligoclase and biotite. The average grain size is 0.5 mm., as compared with a grain size of 4 mm. in the granite.

Intricate graphic intergrowths of quartz and orthoclase-perthite make up the bulk of the graphic granite, and the aplite of quarry 1 is a fine, even-grained rock with rare granophyric intergrowths of quartz and orthoclase.

Petrology of the Tertiary Rocks.

The basalt (Older Volcanic Series), consists of fresh and serpentinised olivine, colourless and pale violet augite crystals, set in a fine-grained matrix rendered dark-coloured by the prolific development of grains of iron ores. The violet augite crystals sometimes possess pale green pleochroic cores. A colourless glass forms part of the groundmass in which are set laths of labradorite, abundant rods of apatite and rare picotite. The phenocrysts are partly corroded by the groundmass, and the felspar laths often stream around them.

The matrix of the river gravels is composed of numerous quartz grains and fine clay particles, with small quantities of the following heavy minerals:—rounded and prismatic zircon, blue, brown, and violet tourmaline often parti-coloured, abundant limonite, rutile, andalusite, and epidote. Leucoxene, rare garnet, zoisite, cassiterite, staurolite, and hematite also occur.

The conglomerate band at The Rocks contains smooth, rounded pebbles set in a sandy to gritty matrix of angular rock fragments up to 5 mm. across, abundant quartz grains, kaolinised felspar and yellowish flakes of biotite. Clay particles are not nearly as common as in the river gravels from the summit of Arthur's Seat. The heavy minerals are similar to those contained in the rocks of the immediate neighbourhood, and from which the constituents of the conglomerate were obtained. The hornblende of the heavy mineral assemblage is quite fresh, and the biotite has only been partially bleached, indicating that the constituents of the conglomerate were not subjected to very much transportation.

The incoherent sandy deposits overlying the conglomerate at The Rocks contain 65 per cent. of grains over 0.5 mm., in size, 21.6 per cent. of grains between 0.5 mm. and 0.05 mm., and 13.4 per cent. of very fine clay particles. The bulk of the larger grains is composed of quartz, and the heavy minerals, which make up only 0.2 per cent. of the deposit, consist of brown and blue, rounded tourmaline grains, hornblende, rounded and prismatic zircons, occasional biotite, rutile, limonite, hematite, andalusite, leucoxene, and rare augite.

Conclusions.

At Arthur's Seat, the most southerly and smallest recorded dacite outcrop in Victoria, the associated igneous plutonic type is a granite, whereas in the dacite regions of Central Victoria, the intrusive rock associated with the dacitic lavas is granodiorite (7, 10, and 18). In the Dromana district, differentiation is therefore considered to have advanced to a greater degree than in the Palaeozoic petrographic provinces of Central Victoria. The Dromana dacites differ from those at Macedon, Warburton, Healesville, and Upwey in the presence of hornblende and the absence of hypersthene. The presence of the primary hornblende at Arthur's Seat is probably due to the fact that the volatile components of the magma were retained until the crystallisation of the hornblende dacite was practically complete, for Kennedy considers that any magma from which hornblende would crystallise under conditions tending towards the retention of the volatile components, would under effusive conditions (with the escape of volatiles), give rise to pyroxenes (14, p. 207).

Where the dacites are metamorphosed in the Macedon and Selby districts, biotite has been formed from hypersthene, while at Dromana, secondary hornblende is produced at the expense of biotite, indicating a higher temperature for the Dromana intrusive rock. At Mt. Leinster, the temperature of the intrusion must have been still higher, since the higher temperature mineral augite has been formed from biotite in the contact rocks.

Regarding the order of appearance of the Palaeozoic igneous rocks in the Dromana petrographic province, the oldest rock, the hornblende diorite is the most basic, and it most probably represents the chilled edges of a dioritic magma, which occupied the magma chamber early in the stages of the processes of magmatic differentiation which ultimately produced a granite. The hornblende dacite is the volcanic equivalent of hornblende diorite, so that by roof fissuring, portion of the hornblende diorite magma escaped to the surface as a lava flow. The vents through which this portion of the magma reached the surface would eventually become sealed, and differentiation processes continued in the magma chamber until the composition was analogous to that of granodiorite. At this stage, further roof fissuring occurred, and rhyodacite was poured out at the surface, the rhyodacite being the volcanic equivalent of granodiorite. After this second outpouring of magma, the vents were sealed up, and remained sealed whilst the magma, gradually becoming more granitic in composition, stoped its way upwards, and differentiation and sinking of assimilation products continued, until the magma finally crystallised as a potash granite. The remaining acidic liquors of the intrusion were then injected through the older rocks, probably in the order granite porphyry, granophyre, felspar porphyry, microgranite, graphic granite, aplite, and finally quartz veins, thus closing the magmatic activity of the Dromana province.

The absence of a floor of Ordovician rocks for the extruded dacites, may be attributed to assimilation and removal during the intrusion of the granite magma, rather than to wholesale roof foundering. The dacites are thus thought to have reached the surface through numerous small fissures, which did not give rise to any widespread or great thickness of lavas, as in Central Victoria, and which would, on account of their small size, be more readily sealed up after extrusive activity had occurred.

In regard to the association of diorite and granite, Daly quotes examples where these two rocks are syngenetic, and he states that the diorite appears to be an older chilled phase of the batholith in which the granite differentiated (4, p. 245). At Dromana, similar conditions might have obtained, but only on a small scale, since the granitic intrusion is a relatively small stock. The differentiated liquid produced in the manner suggested by Daly, would possess greater corrosive powers, and renewed eruptivity would occur after the formation of the chilled phase. The granitic magma would not be in equilibrium with the already chilled, solid diorite, and so would begin to absorb it, but solidification occurred before total engulfment of the chilled phase, leaving xenoliths and streaks of the diorite in the granite of the south-west portion of the stock at Dromana.

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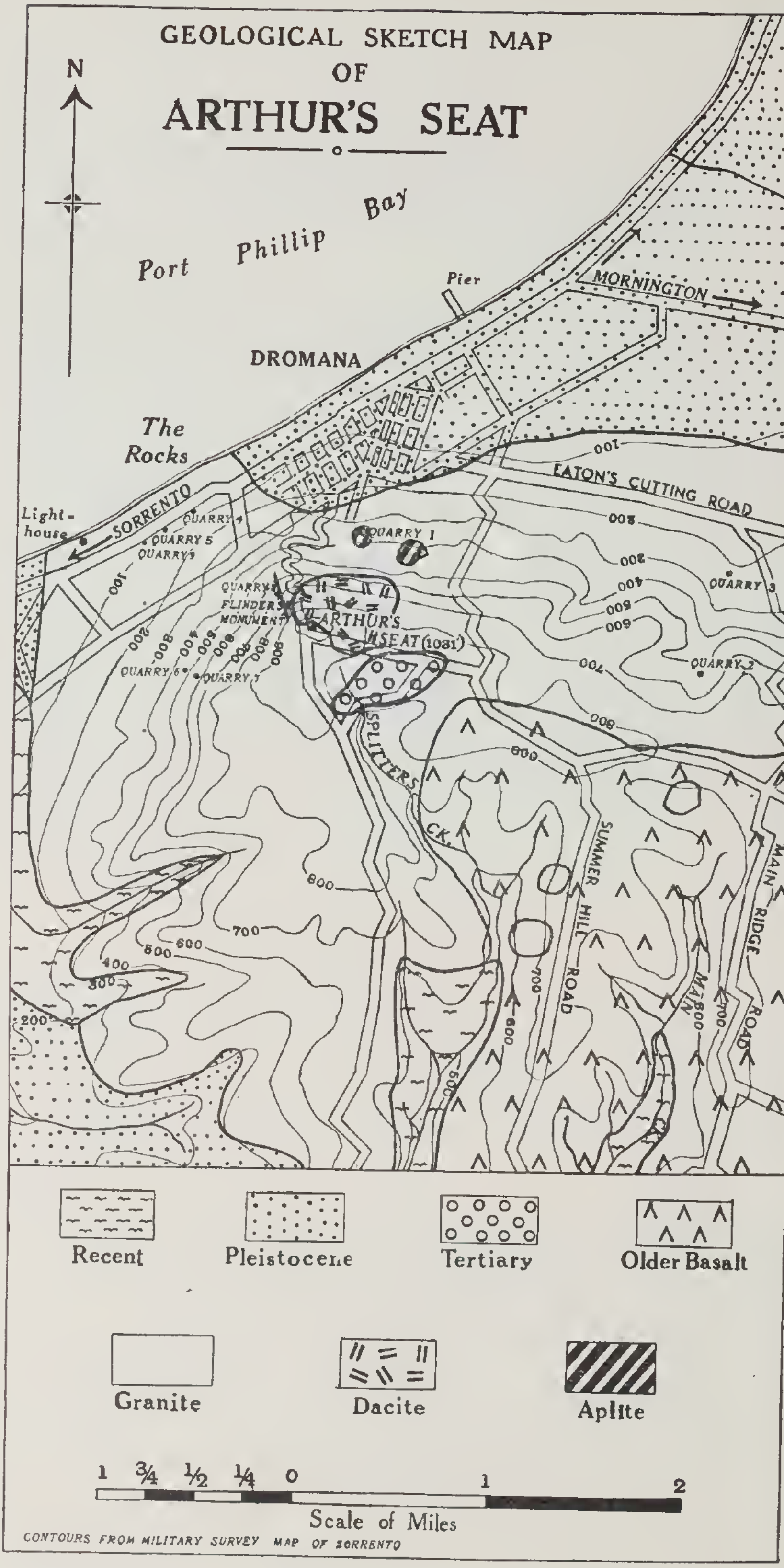
GEOLOGICAL SKETCH MAP
OF
ARTHUR'S SEAT
N
Port Phillip Bay
Pier
MORNINGTON
DROMANA
The Rocks
EATON'S CUTTING ROAD
Light-house
SORRENTO
QUARRY 4
QUARRY 5
QUARRY 1
QUARRY 3
QUARRY 2
QUARRY 6
QUARRY 7
FLINDERS MONUMENT
ARTHUR'S SEAT (1031)
SPLITTERS CK.
SUMMER HILL ROAD
MAIN RIDGE ROAD
Recent
Pleistocene
Tertiary
Older Basalt
Granite
Dacite
Aplite
1 ¾ ½ ¼ 0 1 2
Scale of Miles
CONTOURS FROM MILITARY SURVEY MAP OF SORRENTO